

# Early Beam Injection in the Fermilab Booster & its Implementation Plan

Chandra Bhat

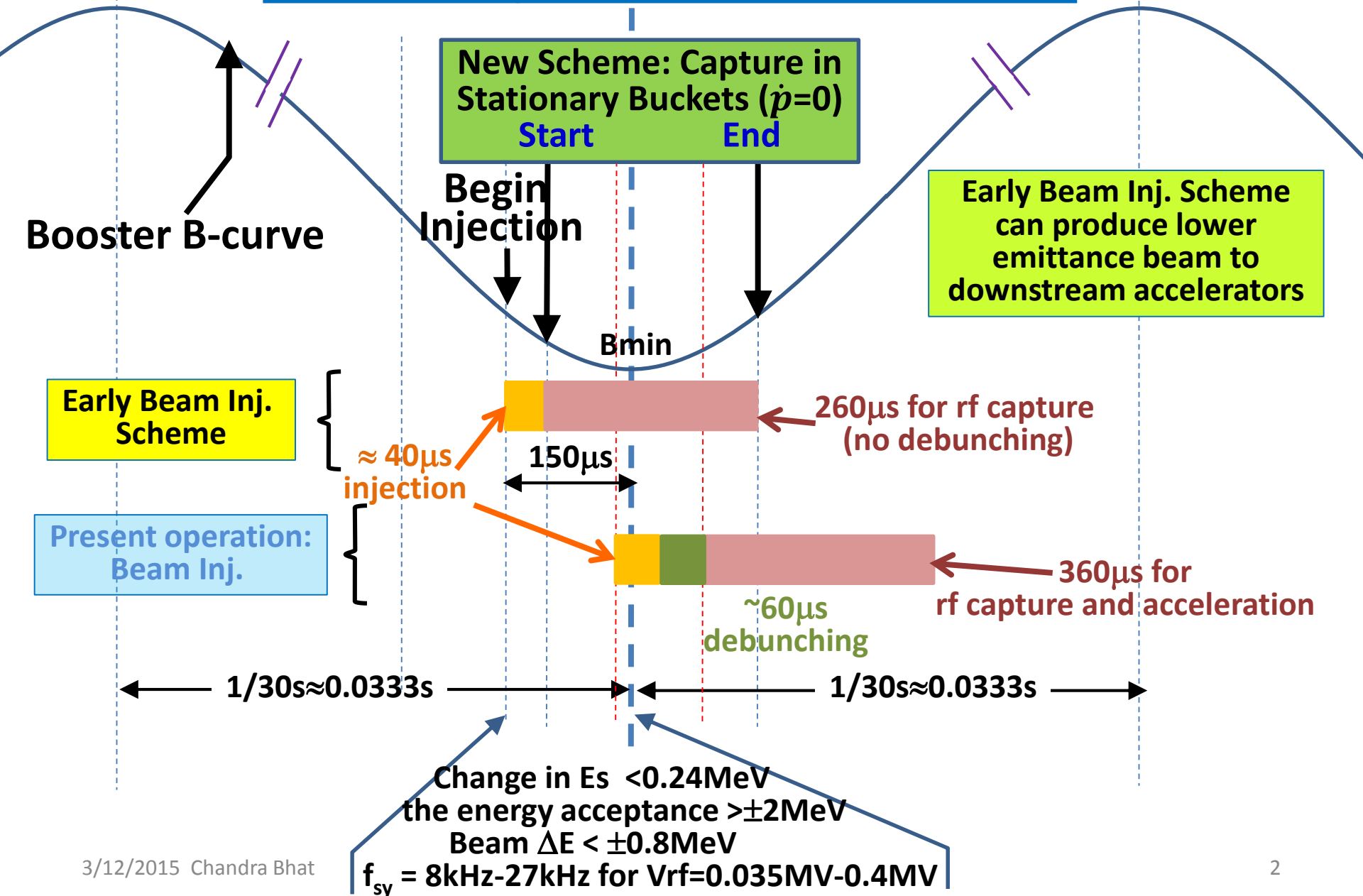
Todd's Operation Meeting

20150212

## Abstract:

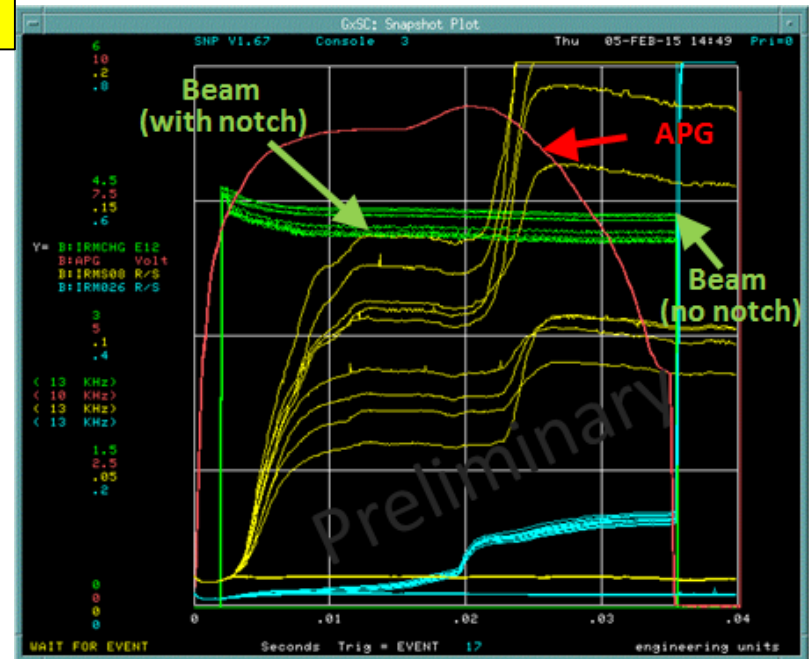
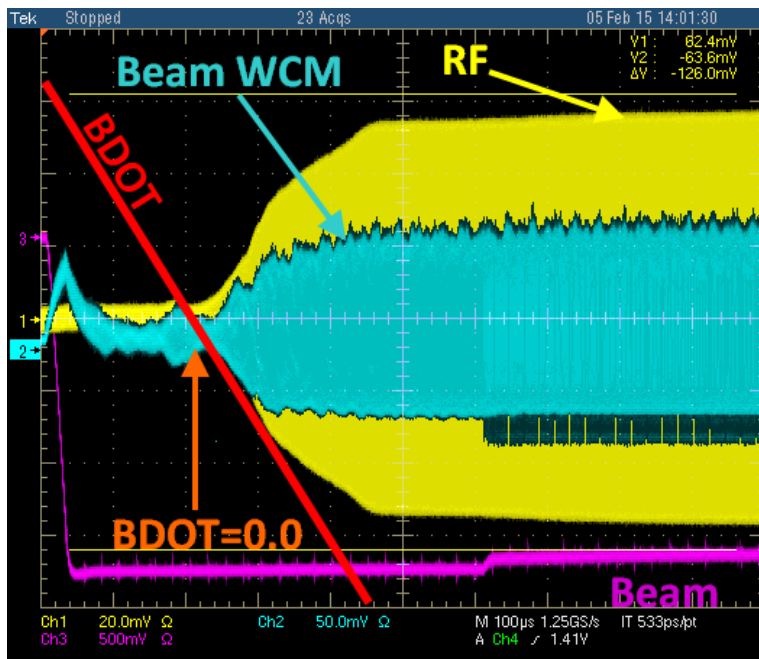
Over the past 6-8 months we have made significant progress in understanding the Early Injection Scheme (EIS) via simulations as well as by the experiments in the Booster. The studies needs dedicated beam time, hence, we developed 1-shot sequence which will help us to make progress in the beam studies even during the nominal beam operation. The results from the simulations on the EIS shows that one can operate Booster at a lower rf power, produce lower emittance beam and no beam losses under current operational scenario. The conclusions from a preliminary analysis (presented here) of the beam data from EIS are, 1) one can lower the rf power by ~15%, 2) beam delivery efficiency is about 90%, comparable to that with the current operation, even with a part of the scheme implemented in the tests. We present game plan for implementation of the full scheme in operation.

# Beam Capture in the Booster

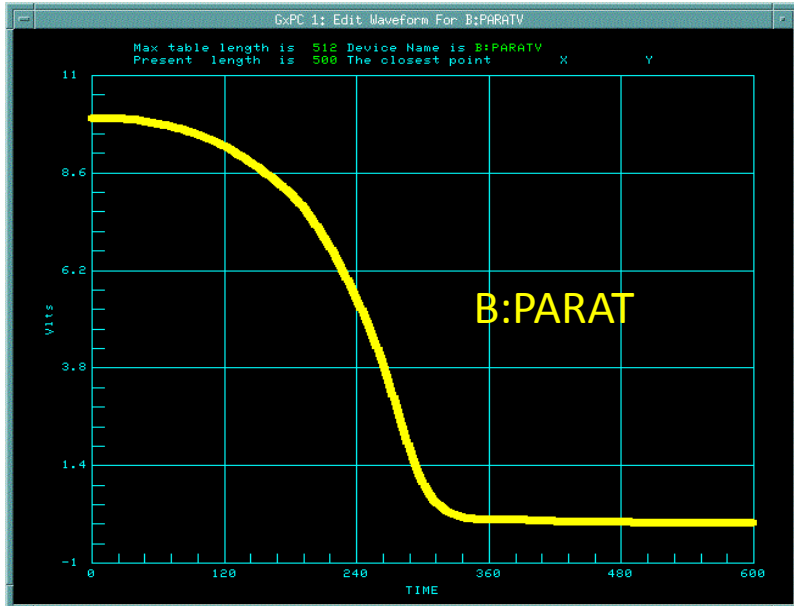
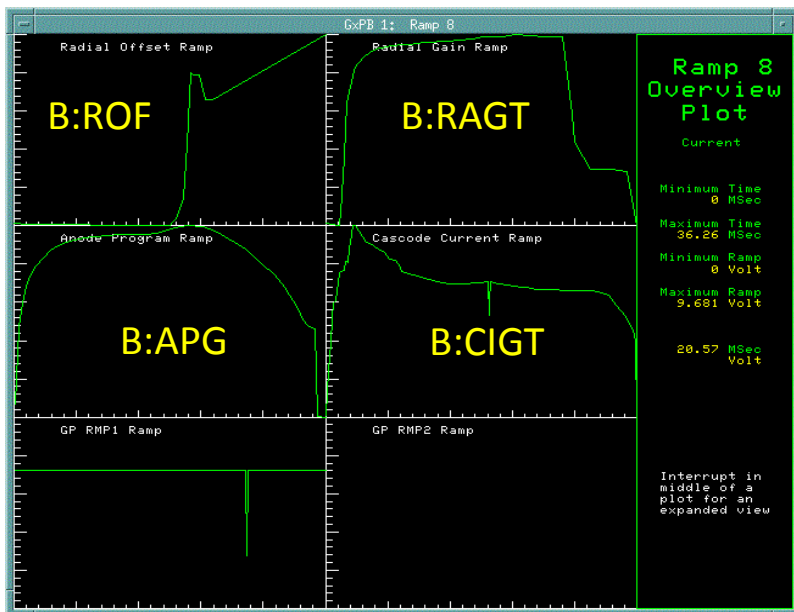


# Beam Studies on Early Injection Scheme

- ❑ The Beam studies were made on \$17
- ❑ Following Changes were made:
  - beam injection at 144  $\mu\text{s}$  earlier than BDOT=0.0
    - $\Rightarrow$  B:RSTDLY changed to 64491 $\mu\text{s}$  from nominal value of 64635  $\mu\text{s}$
  - New RF, ROF and Paraphase curves, B:VFINJ
  - Additional tuning was needed at transition crossing (some times)



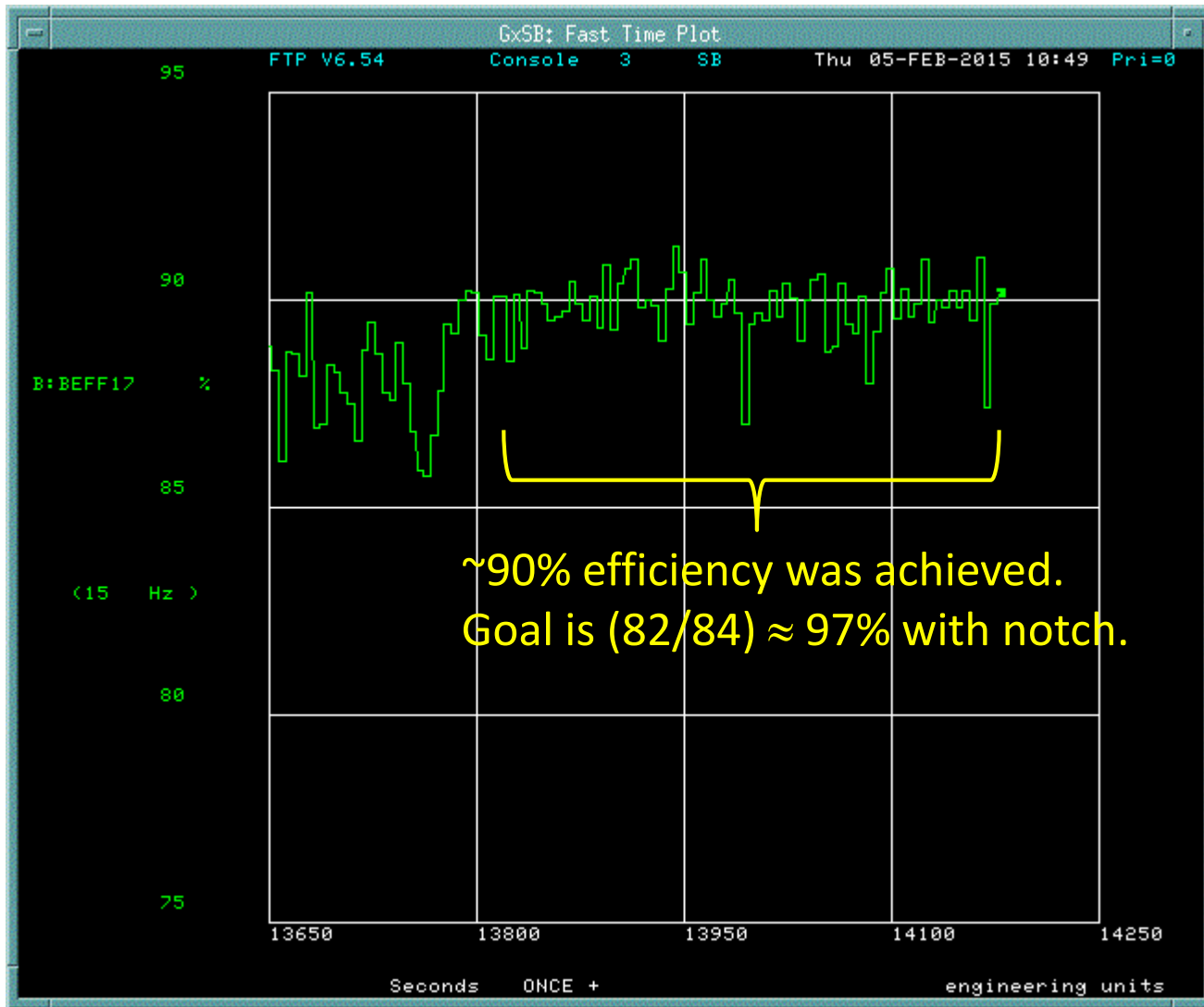
# New Settings for a few Parameters



PA B9 PARAM

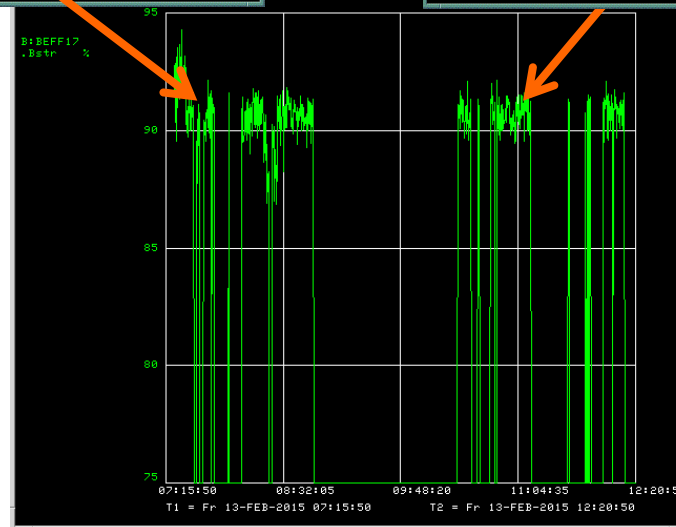
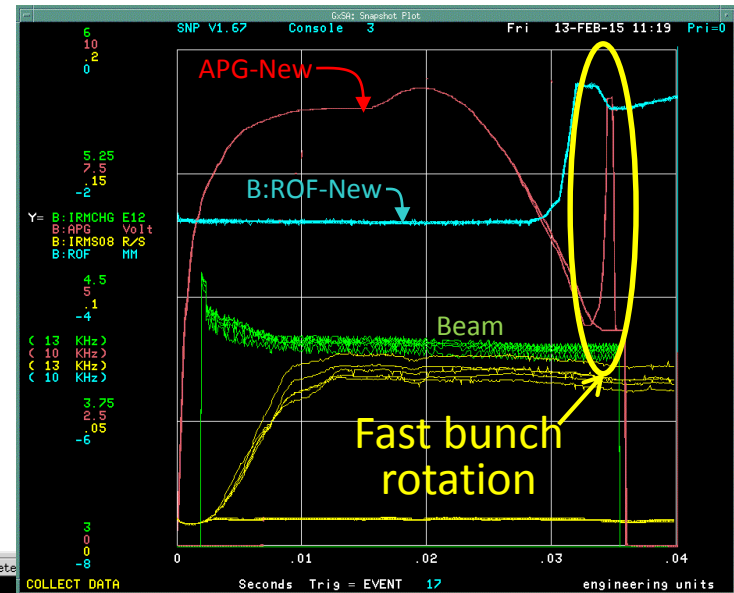
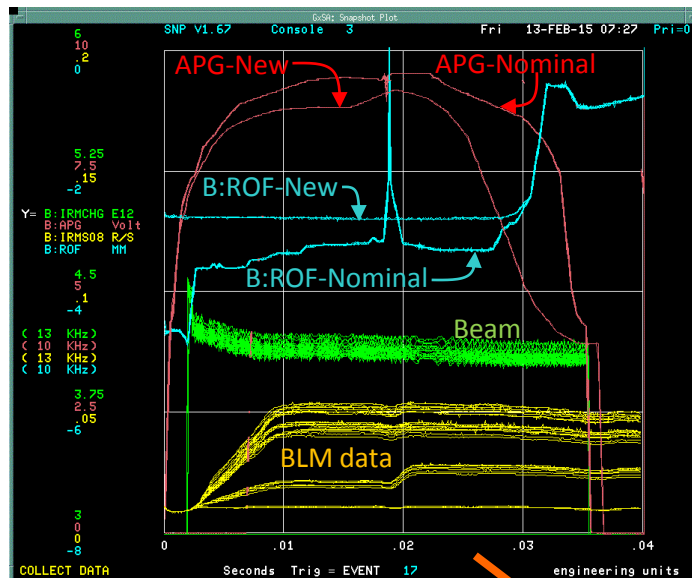
B9	Parameters	-II (CMB)	SET	D/A	A/D	Com-U	◆PTools◆
-<FTP>+ *	SA	X-A/D	X=TIME	Y=L:QPS412,L:QPS413,B	BLM011,B	BLMS06	
COMMAND	----	Eng-U	I= 0	I= 127.984, 138	, 0	, 0	
-< 8>+ One+ AUTO	F= 1800	F= 152.016, 150	, .2	, 6			
BPM_400	.gmps.. rad_mon irms	tunmetr dampers bpm-400	.montr.				
! Booster Inj. LLRF control paramters							
-B:VCDLY	BLLRF Curve Delay	74	74				clks
-B:VFIDR	BLLRF Inject Freq Dec	332	332				usec
B:IRMPDD	IRM Peak Diode Detector		0				V
-B:CIGL [6]	Cascode I 473 Delays	120					uSec
-B:APGL [6]	Anode Pgm 473 Delay	52	42				uSec
-B:ROFL [6]	Radial Offset 473 D	30	190				uSec
!only for testing							
-B:VXTPPP	NEW VXI Para pgm tr	2055	2160	2160			uSEC ....
-B:VAPLON	Acceleration PL gat	2130	2270	2270			uSEC ....
-B:TFBON	TRANSFR BEAM FEEDBA	2150	2390	2390			uSEC ....
-B:VFINJ	BLLRF Inje	37.923581	37.937095	37.937094			MHz
-B:TNOTCH	Notcher Trigger	2400	2400				USEC ....
-B:TTRX17	Transition Gate ON	18758	18754	18754			USEC ....
-B:TTPS17	Trans Phase Shift Dly 17	18733	18733				USEC ....
-B:RSTDLY	Bstr Reset Delay to	64635	64491				USEC
-B:TNOTCH	Notcher Trigger	2400	2400				USEC ....
-B:NKDCGU	NOKD Charge Dly Uncogged	2175	* 2175				USEC ....
B:LINFRQ	60 HZ Line Freq Offset		8.002				mHz
B:NOKDP	Power Supply Monitor		2.19				kV
-B:POTAIN	Anode Pot A at Injection	2	2				Volt
-B:POTBIN	Anode Pot B at Injection	0	0				Volt
!400MeV debunchercavity phase							
-L:CDPHAS	Acceler Cavity RF Phase	282	282.5				DEG
-L:LDPADJ	Cavity Phase Setpoint	120.5	120.5				DEG
-B:PC10FF*.1	Bseline of	-.1304878	-.12073171	-.12073171			volt

# Beam Efficiency on \$17 with 13BT



# Studies Continued with B:RSTDLY=64635 (standard Val.)

- ❑ Did continue our beam studies to optimize the APG and ROF curves on \$17, B29 (Ramp 8) to smooth and reduce the RF power.

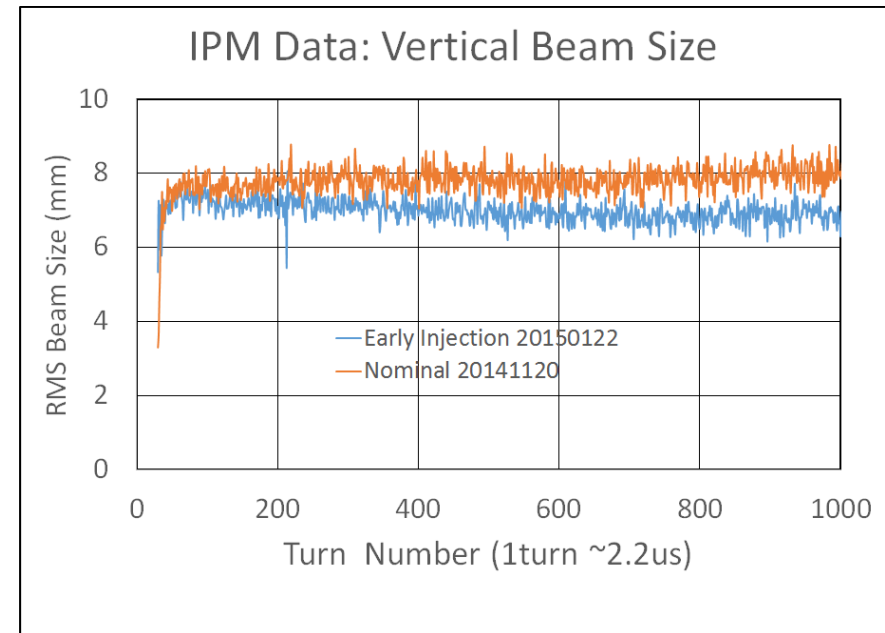
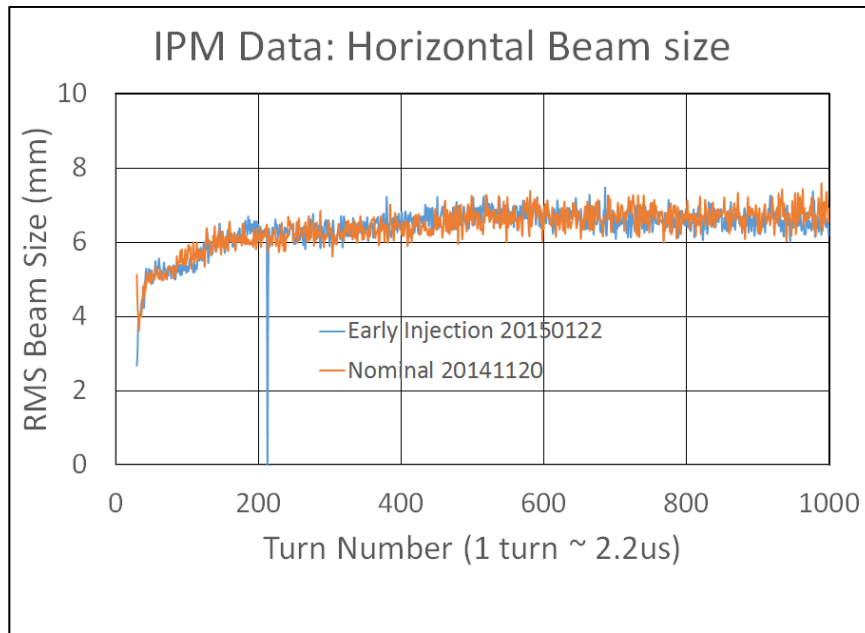


The difference between new and nominal APG (Vrf) curves on the cycle are shown for comparison.

>90% beam efficiency with 13BT.

# Samples of Transverse Beam Sizes for the First 2 ms

Data are for 14BT beam



# Game plan & Issue

- ❑ Early Injection Scheme can be made operational immediately
  - Set the B:RSTDLY = 64491  $\mu$ s
  - Set new values for B:VFINJ, B:TTRXnn (turn dependent), ... parameters indicated in earlier. This enables us to start beam capture immediately after Bmin.
  - Our immediate goal is to provide the beam with efficiency >85% (so far we have proved efficiency ~90% with 13BT).
    - ← We may have to inform the users about this new development and why we are doing this.
- ← No showstopper
- ❑ We will continue to optimize various parameters for better efficiency (similar to what is currently being done). This tuning is transparent to down-stream machines. Also improve on
  - PARAT, APG, ROF ... curves, tune, chromaticity curves etc.,

This gives us an ability to make progress; reaching 97% efficiency with notch in place .



# Game plan & Issue (cont.)

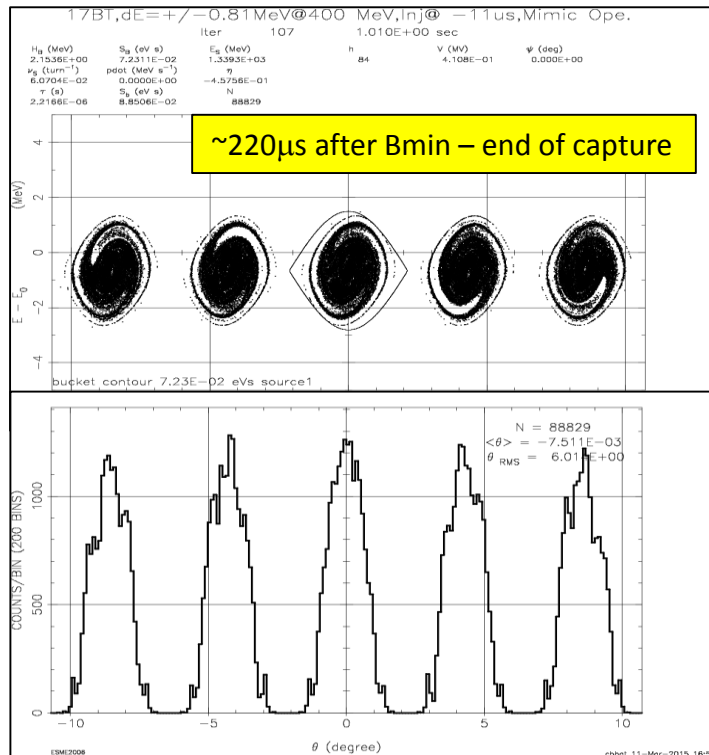
- ❑ So far, we have taken only the partial benefits of Early Injection Scheme, i.e.,
  - Start beam rf capture immediately after Bmin though beam injection is about  $144\ \mu\text{s}$  earlier (in contrast, operationally we wait for 100s of  $\mu\text{s}$  on the up-ramp before rf paraphrase is turned on).
- ❑ To take full benefit we need
  - To move the beam capture soon after the completion of the beam injection, i.e., B:VCDLY and B:VFIDR need to be referenced to TCLK
  - Currently, we use a calculated frequency curve which does not match with the value at injection (therefore we adjust B:VFINJ). We need better frequency synchronization bet. LLRF and real freq..
  - We also work on fast bunch rotation at extraction which is more clean and gives better lower energy spread beam to slip-stacking in RR.
  - If LINAC can give us more number of turns we can accommodate them!

Backup slides

# Simulation of Beam Capture at Injection

Used  $dE_{\text{full}} @ \text{Inj} = \pm 0.8 \text{ MeV}$  (Measured at Inj.)

**Operational Scheme:**  
Beam inj. at  $-11 \mu\text{s}$  w.r.t. Bmin (17BT)

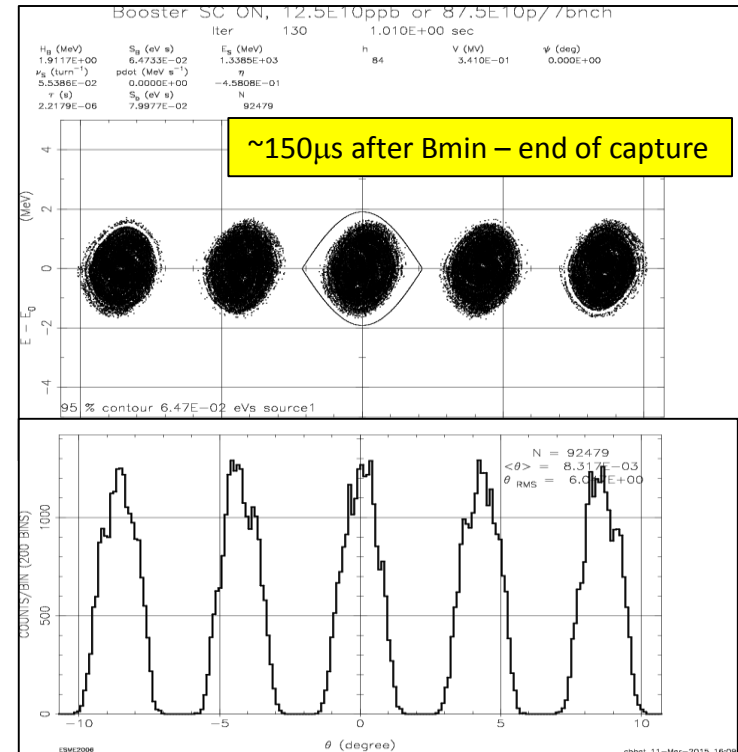


**Bucket Area = 0.07 eVs**

**$\epsilon_L = 0.06 \text{ eVs}$**

**~2% Beam loss  
even without SC effects**

**Early Injection Scheme:**  
Beam Inj. at  $-144 \mu\text{s}$  w.r.t. Bmin (17BT)

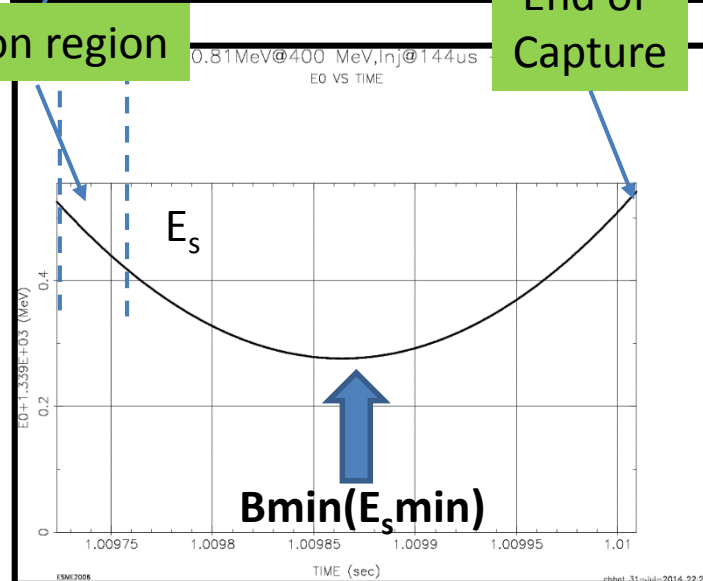
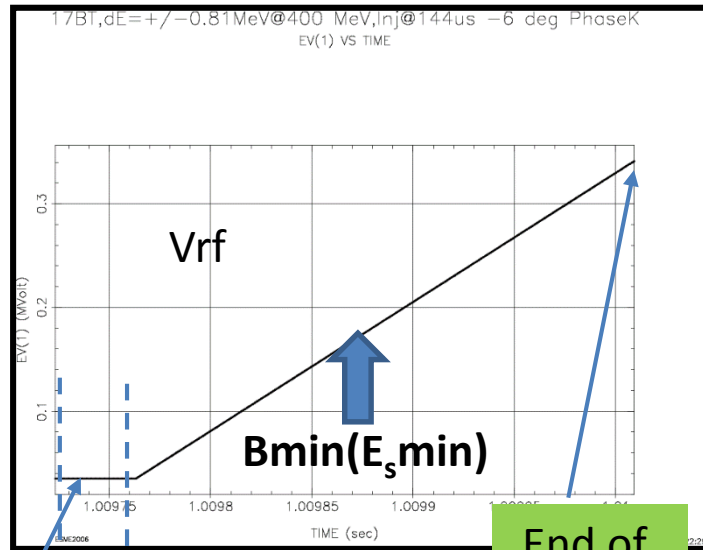


**Bucket Area=0.065 eVs**

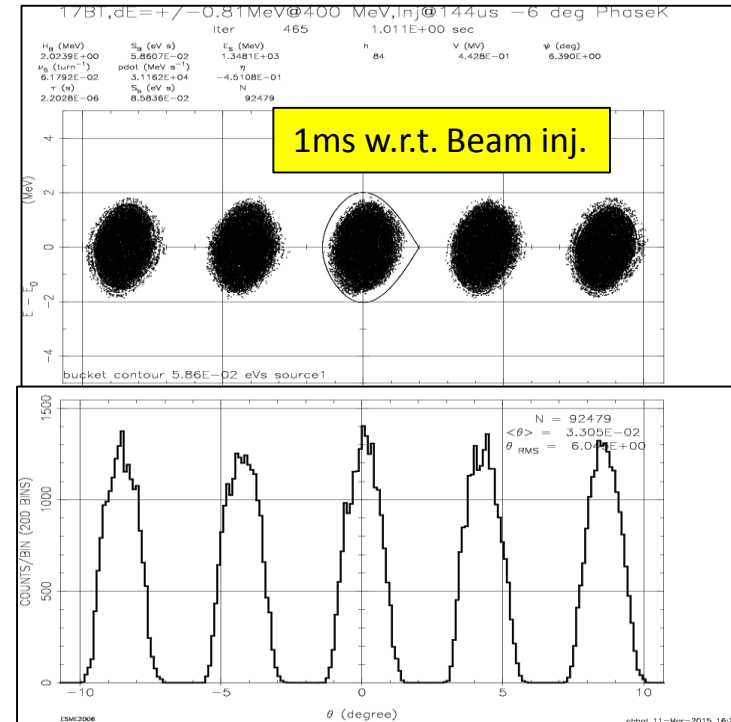
**$\epsilon_L = 0.045 \text{ eVs}$**

**No Beam loss**

# Early Inj. Scheme: Beam at ~1ms w.r.t. Inj.



Beam Inj. at -144 $\mu$ s w.r.t. Bmin (16BT)  
Simulations with longitudinal SC(symmetric)



Vrf (@400  $\mu$ s) = 0.44 MV

Bucket Area=0.06 eVs

$\epsilon_L \approx \pi \times 0.008 \mu\text{s} \times 1.8 \text{ MeV} = 0.045 \text{ eVs}$

No Beam loss even with SC effect

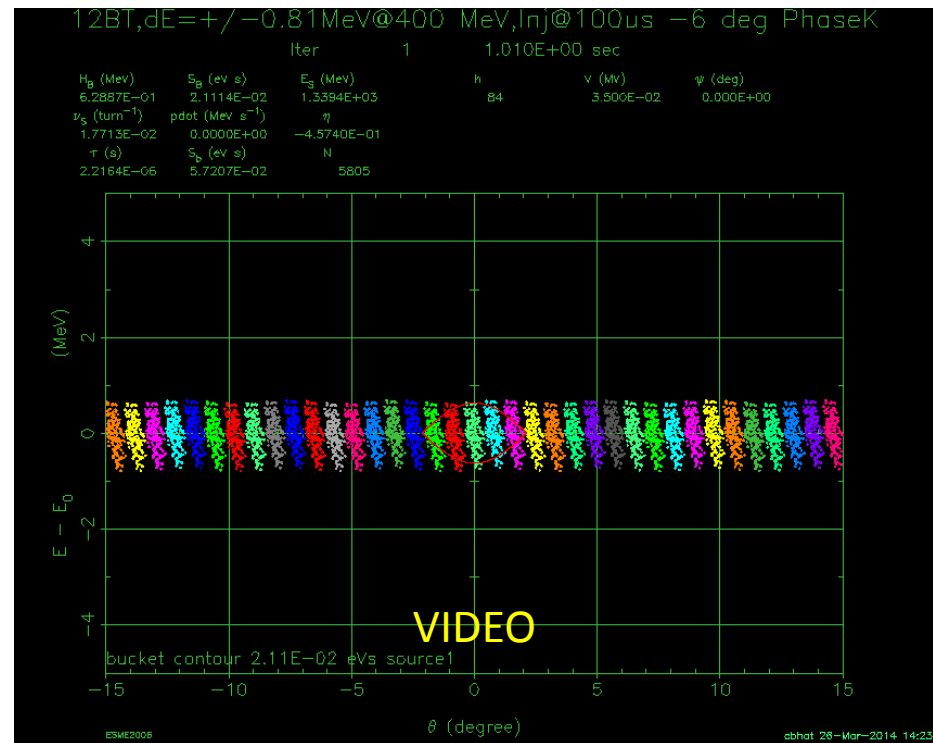
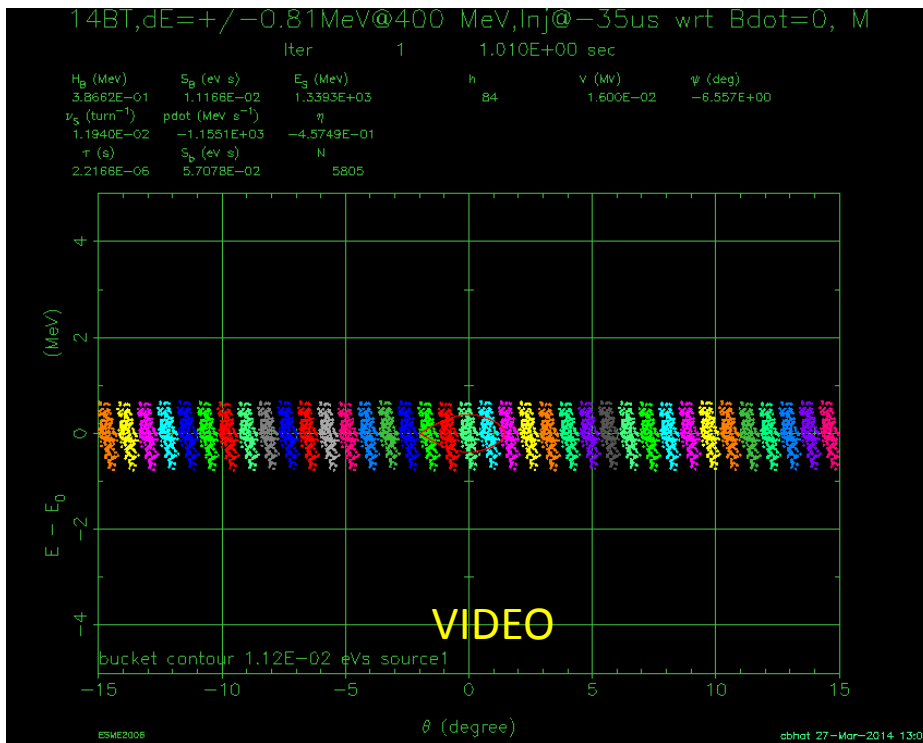
~30% lower rf power on average over the cycle

# Simulation for Injection → Extraction in the Booster

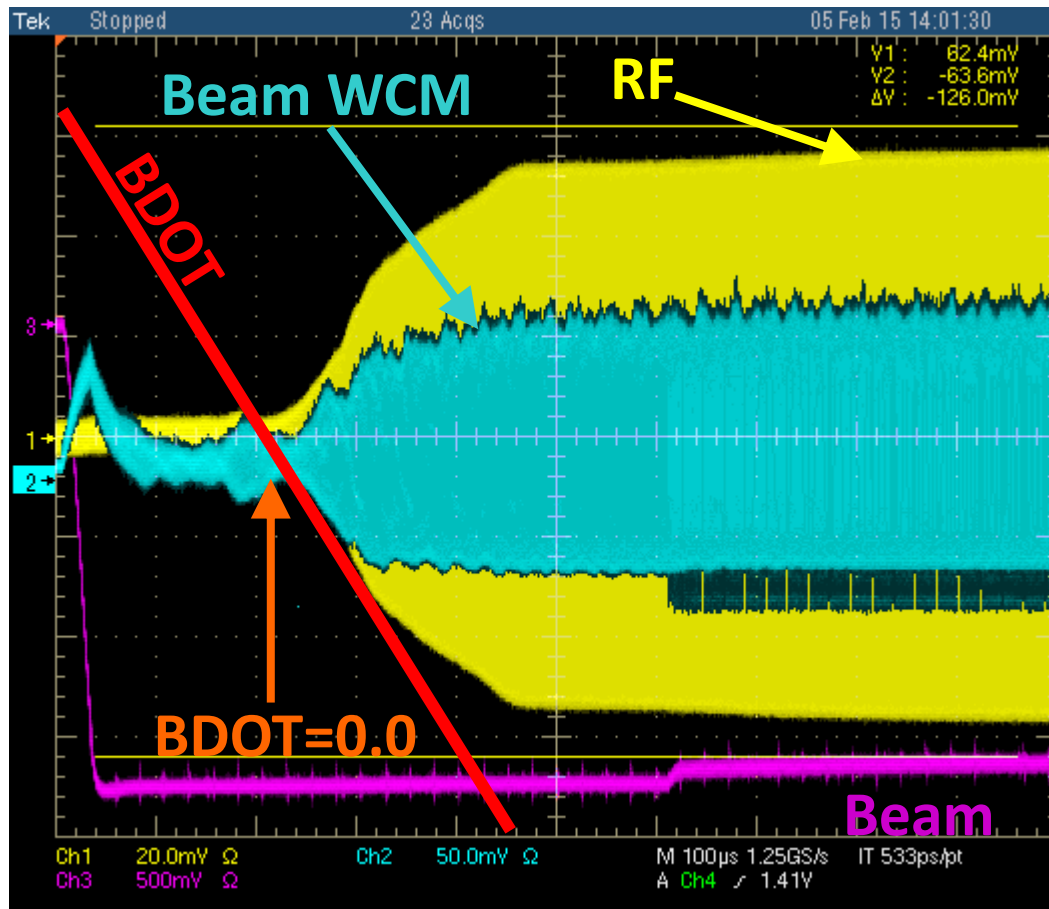
Proposed Scheme: **Inj@Bdot=0 at -100 $\mu$ s**,  
Capture from -64  $\mu$ s to 135 $\mu$ s, with a phase  
kick of  $\sim 6$  deg after transition crossing.

Mimic of Operational Scheme

**This video is for Inj → Extraction**



# Recent Beam Studies on Early Injection

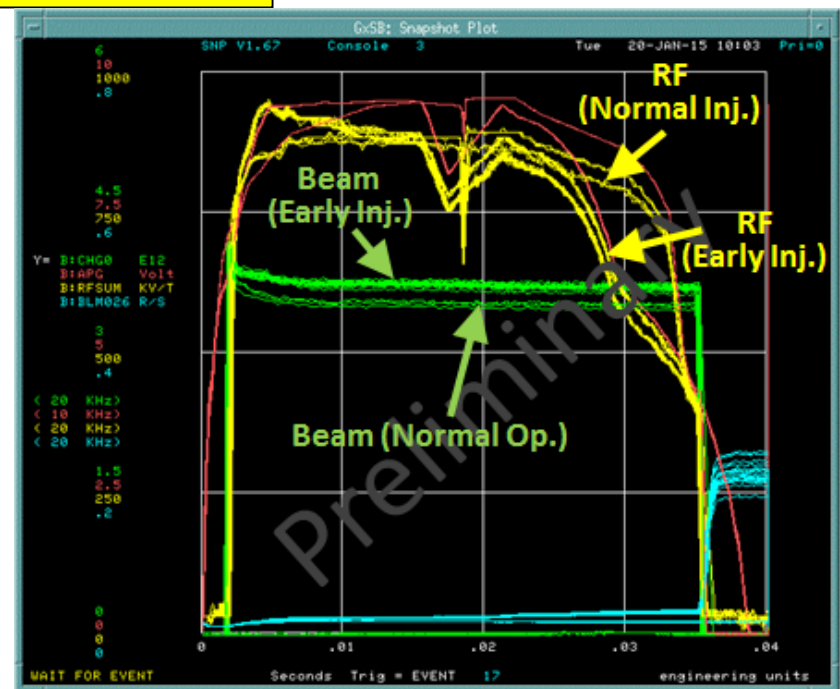
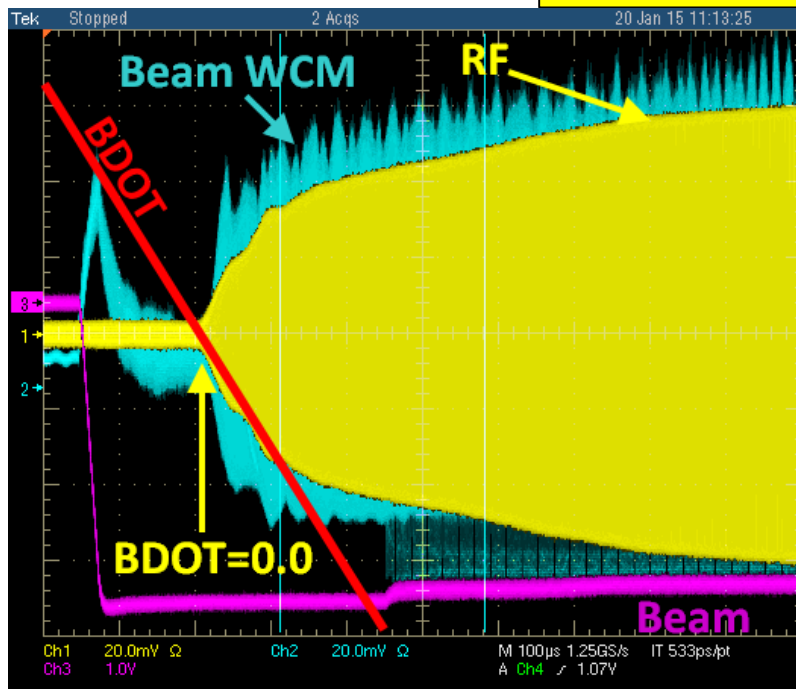


# Beam Studies on Early Injection Scheme

Conditions:

- 1) beam injection at 144  $\mu$ s earlier than BDOT=0.0
- 2) New RF, ROF and Paraphase curves
- 3) Additional tuning was done at transition crossing

12 BT after transition tuning



Flans:

We would like to start beam capture as early as possible after the beam injection with proper frequency curve. This needs some changes to the timing and hardware. This work is in progress.